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# **The application of vertical magnetic contouring in estimating the extent of Precambrian iron formations in the Schefferville district**

by  
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Vorgelegt von **André Cailleux**

## **Abstract**

Magnetic surveys were conducted at surface and at different altitudes over magnetic taconite iron deposits. The magnetic observations are presented under the form of vertical sections. This information allows on-site experimental optimization of flight line spacing and flight altitude for aero and helicopter borne magnetic surveys which are under way or are planned for future exploration programmes.

It also provides a means for determining the width of the buried causative body, its depth of burial below the plane of observation and the relative importance of the natural remnant magnetic component. A great many examples selected on a large variety of sites underlain by magnetic taconite deposits allowed a comparison of the calculated parameters with actual depths, widths and natural remnant magnetic vectors. A few of these vertical magnetic sections are presented in this paper.

## **Introduction**

The surface expression of the magnetic taconite iron ore deposits is that of a country of low, gently rolling hills, cut by occasional scarps. The hollows are filled by lakes and muskeg swamps. The climate is typically sub-arctic with discontinuous permafrost spread over the area. During the summers of 1943 and 1944, prospecting and geological mapping were conducted and by 1954, an excess of 400 million tons of direct-shipping ore ( $>50\%$  Fe) was proven. In 1972, 175 million tons had been mined out by open-cast methods. The same year, the operation of a new beneficiation program was begun and some 200 million tons of treat rock ( $40\text{--}50\%$  Fe) had been proven. A preliminary evaluation of the economic potential of the magnetic taconite deposits in the Schefferville area was carried out by Seguin (1966a, b, c, d, e). The high-grade magnetic taconite ( $30\text{--}35\%$  Fe in the mineral: magnetite) of the Howells River area were surveyed with a ground magnetometer in 1967 and 1968 (Seguin 1967a, b, c, 1968a, b, c, d, 1969a, b, c) and with a heliported magnetic system in 1971 (Seguin 1970, 1971a, b). The deposits of the Howells River areas were tonnage drilled in 1970 and 1971. In the Knob Lake Ridge region, the ground magnetic surveys were conducted in 1968 (Seguin 1968e, f, 1969d, e, f) and the helicopterborne magnetic survey in 1972 (Seguin 1972).

### Geology

The oldest rocks mapped in the area are highly metamorphosed basement granite gneisses which are located to the west of a thick sequence of Lower Proterozoic (Aphebian) rock types overlying them. The succession of formations which compose the geological group usually called the Labrador Trough consists, from bottom to top, of siliceous slates (Attikamagen), dolomite (Denault), chert breccia (Fleming), ortho-quartzite (Wishart), iron-rich slates and chert (Ruth), iron formations (Sokoman) and graphitic slates (Menihek). On the western edge of the trough, in the vicinity of the unconformity with the Ashuanipi Archean basement gneiss, the Attikamagen, Fleming and occasionally Wishart formations are absent; this is the case in the Howells River area, for instance. The iron formation which is the geological unit of particular economic importance is subdivided into three members which are:

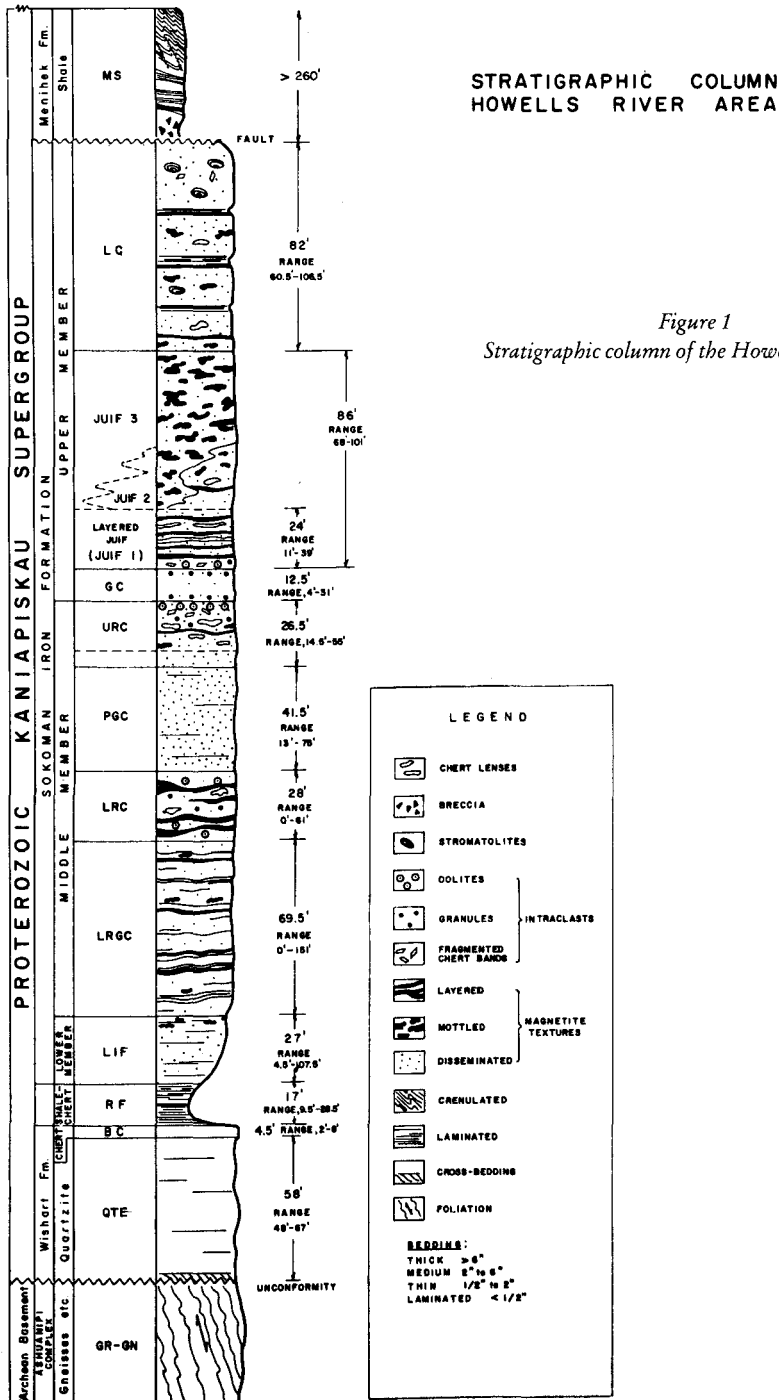
- 1) The Lower Iron Formation (LiF, LG and SCiF) which is mainly composed of iron carbonates, silicates and magnetic; thickness may vary from 10 to 80 feet (3–24 m).
- 2) The Middle Iron Formation composed of iron oxides (metallic blue hematite and magnetite with chert); true thickness ranges from 100 to 250 feet (30 to 75 m).
- 3) The Upper Iron Formation consisting of iron carbonates and oxides (mainly magnetic) and chert with a thickness ranging from 40 to 120 feet (12–40 m).

The total thickness of the iron formation members varies between 300 and 500 feet (100–165 m). A stratigraphic sequence of the iron formations of the Howells River area is shown in figure 1.

In a few locations, the iron formation is cut by thin subvertical diabase dykes. On the western edge of the Labrador Trough, the formations are almost entirely undeformed. In the main mine zone located some 10 miles (16 km) further east, they are intensely faulted and folded; some 15 to 20 miles (24–32 km) still further towards the east, they are severely folded (overturned in 95% of the cases) and interbedded with volcanic (meta-andesites and meta-basalts) and volcanoclastic rocks. That their grade metamorphism is low in spite of their structural complexity is unusual.

Due to leaching processes which have occurred mainly within the orebodies of the central sector (main ore zone), most of the direct shipping and treat rock soft ore types are commonly very porous. Leaching of carbonates is the most widespread feature but even components of silica and iron silicates are leached, chert breaking down to chert breccia and quartzites to sand. In addition, iron and manganese oxides occur as fracture fillings and are found in the pore spaces left by leached minerals; the major part of this enrichment in iron and manganese took place in the Mesozoic Era (Upper Cretaceous).

The largest blocks of high grade taconite are found in the western edge of the trough where the undisturbed structural situation is prominent (see Figure 2). Additional smaller masses of magnetic taconite are found in thick unaltered impermeable and deeply folded iron formation bodies. Figure 3 shows a geological plan of the Howells River magnetic taconite deposits and Figure 4, a typical geological section through the orebody.



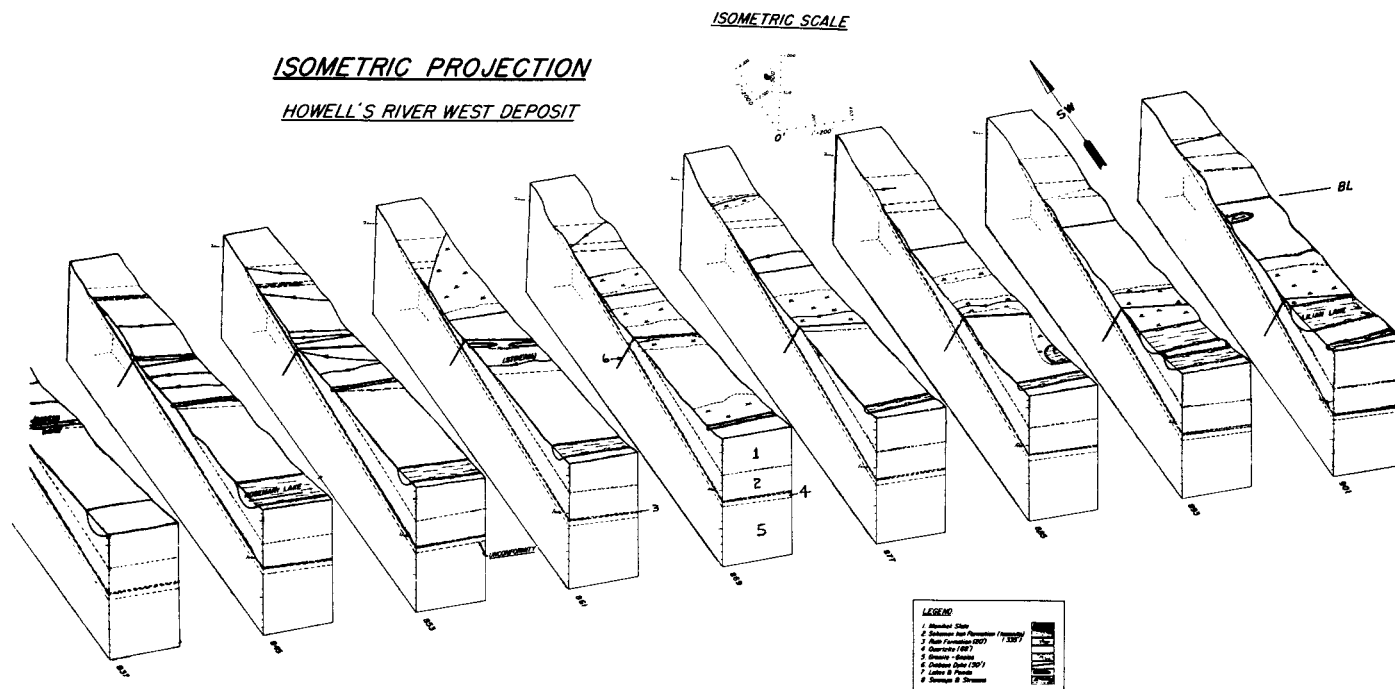


Figure 2  
Block diagram of Howells River magnetic taconite deposits



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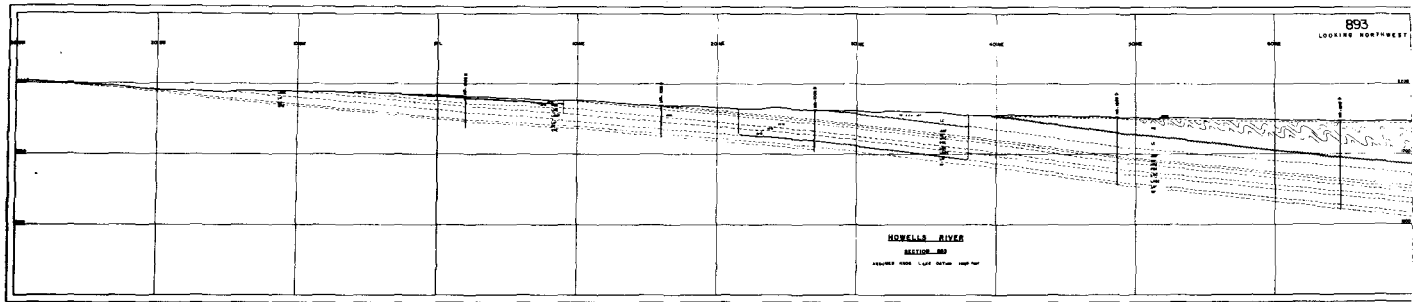


Figure 4  
Generalized geological section of the area presented in figure 3

### Magnetic Surveys

A total intensity aeromagnetic survey was first conducted in 1951 and later in 1962 on the magnetic taconite deposits and the surrounding areas. The observations were made with a standard Gulf Mark III fluxgate magnetometer towed in the rear of an aircraft. The mean terrain clearance for the survey was 500 feet (150 m) and the flight line spacings were one half or one mile (0.8–1.6 km) apart. A magnetic contour map constructed from this survey on the Howells River and Knob Lake Ridge areas are shown in Figure 5 and 6 respectively.

Additional total intensity data were collected in 1971 and 1972 above the different orebodies at altitudes of 125 and 250 feet (38 and 75 m). Navigation control of the first aerial magnetic survey was carried out using aerial photographs for position reference. In the subsequent helicopter surveys, a tracking 35 or 16 mm camera coupled to the magnetic recorder (on paper and magnetic tape) allowed more accurate recovery of the actual flight paths. Altitude positioning was controlled by reference to a Bonzer radio altimeter. It is estimated that the lateral and vertical controls held the aircraft and helicopter within approximately 5 to 10% of the specified terrain clearance.

All the surface magnetic observations were obtained with a Scintrex MF-1 fluxgate magnetometer measuring the vertical component of the earth's magnetic field.

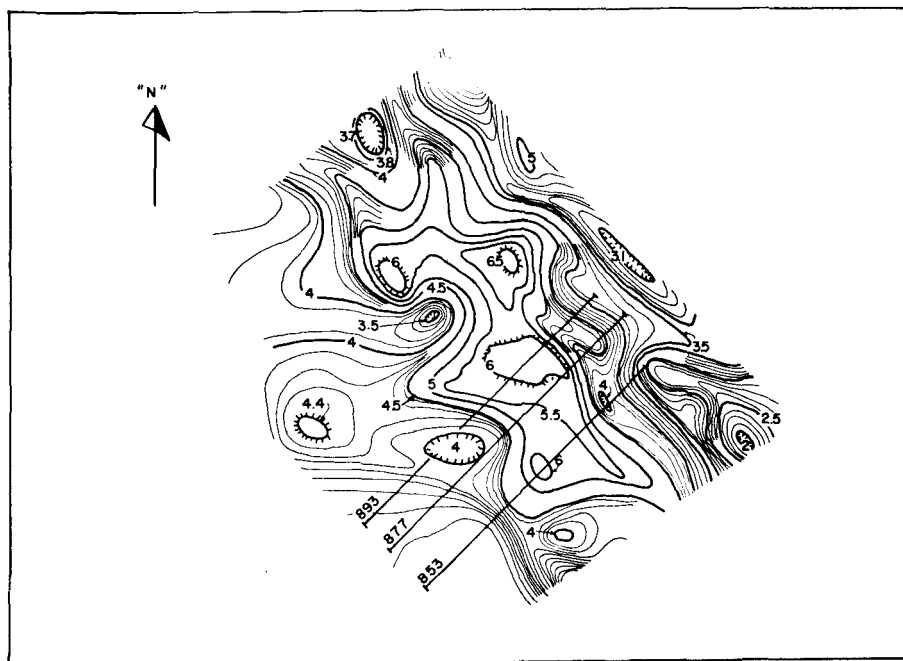


Figure 5

*Aeromagnetic contour map of the Howells River area. The average flight height is 500 feet (150 m) and the values on the contour lines are represented by intervals of 1000 gammas.*



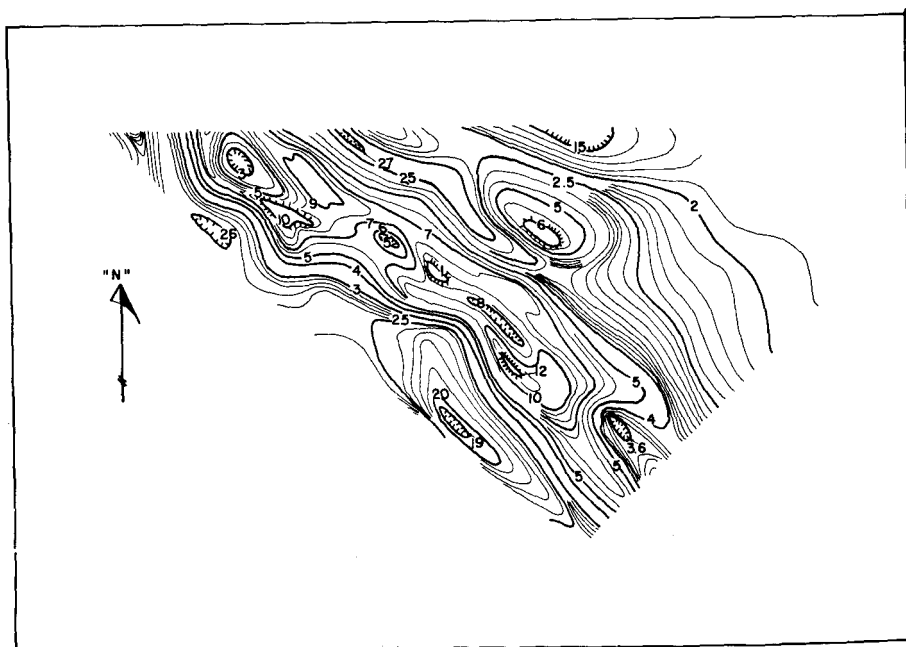


Figure 6

*Aeromagnetic contour map of the Knob Lake Ridge area. The mean terrain clearance is 500 feet (150 m) and the values of the contour lines are represented in intervals of 1000 gammas.*

### Data analysis

The multilevel magnetic observations were plotted in plan and section to determine the configuration and intensity of the magnetic field over the different deposits of magnetic taconite and the surrounding rocks. Figures 7a, b, c and 8a, b, c present the magnetic information plotted in vertical section with contour lines through points of equal magnetic intensity for section lines 853, 877 and 893 of the Howells River deposit and lines 60, 81 and 102 of the Knob Lake Ridge deposit. Surface geology and geologic sections of the Knob Lake Ridge area are published in Seguin (1963). Contour maps of the ground and airborne magnetic data are presented in Seguin (1971c, 1973b).

Multilevel studies have been previously carried out by Wahl-Lake (1957) and Westphal (1960) and the vertical section method of mapping magnetic anomalies as a mean of viewing magnetic information has been used by Riddell (1967) at the Dayton iron deposit, Lyon County, Nevada, U.S.A.

In the examples shown in this paper, total intensity airborne data have been combined with vertical intensity surface data. As the vertical component of the field in the vicinity of the orebodies represents approximately 95% of the total component, the discrepancies so introduced are not large. A common datum for surface, air- and helicopterborne values was chosen from an area of low magnetic relief that lies north-east and south-west of the ore deposits.

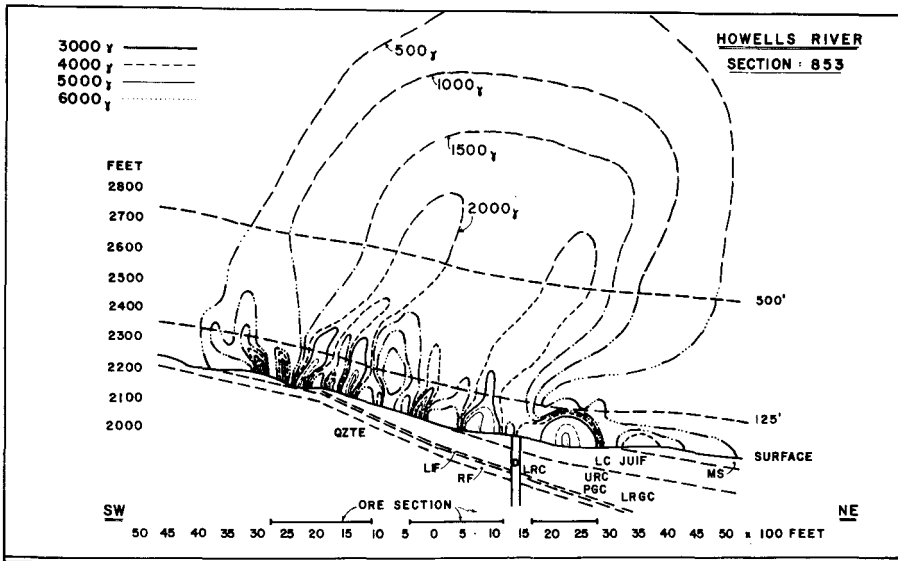
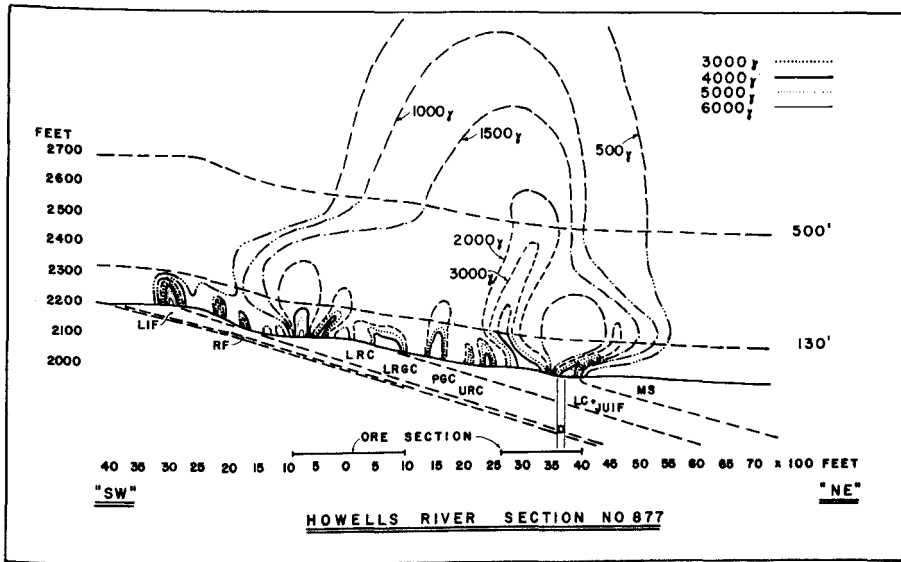


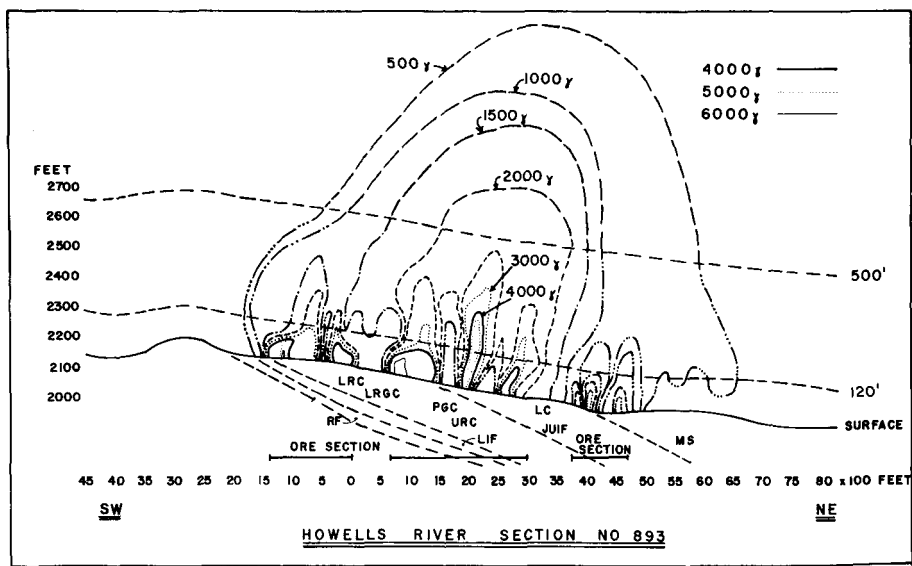
Figure 7

Vertical sections with equal intensity magnetic contour lines on the Howells River deposit

a) Section line No: 853



b) Section line No: 877



c) Section line No: 893

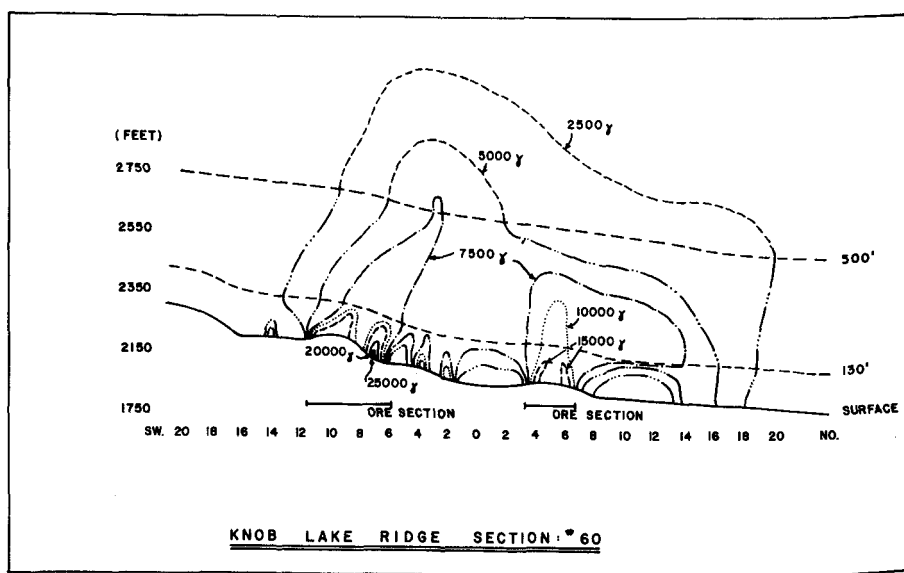
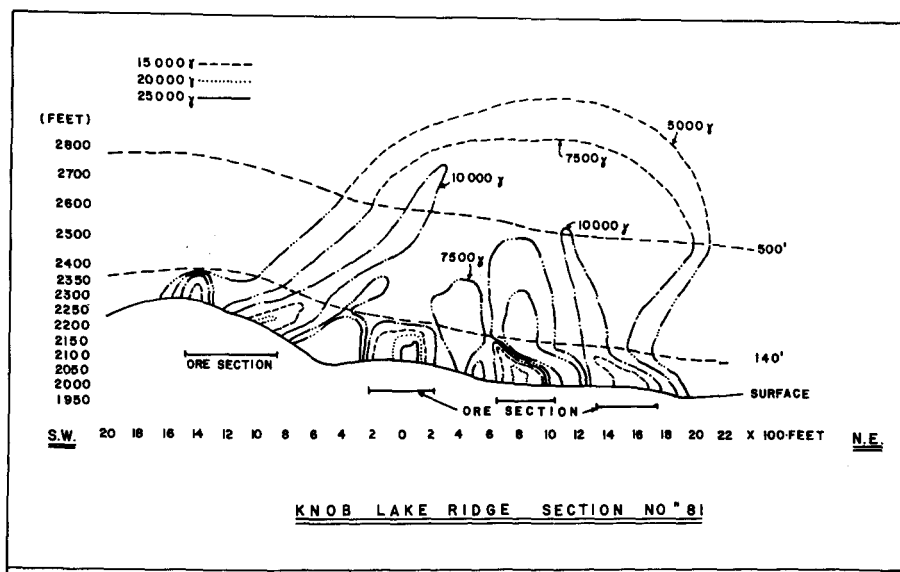


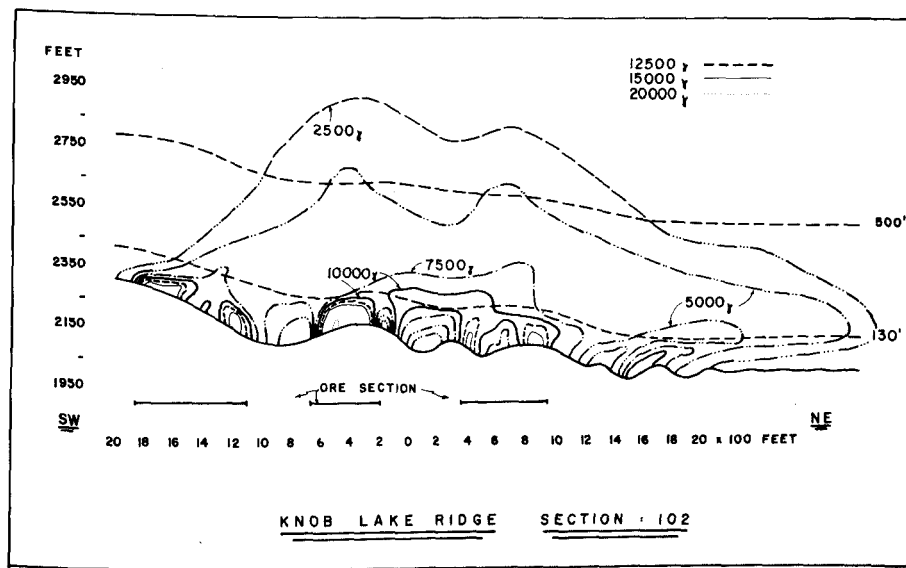
Figure 8

Vertical sections of equal intensity magnetic contour lines on the Knob Lake Ridge deposit:

a) Section line No: 60



b) Section line No: 81



c) Section line No: 102

Several factors are readily apparent on viewing the magnetic sections of the two deposits selected:

- The northwest-southeast profiles depict a better lateral symmetry while the northeast-southwest profiles show distortion mainly caused by the inclination of the earth's field and the variable northeastern dip of the iron formations. However, under the condition in which the flight lines are run in the northeast-southwest direction, the chances of missing a magnetic taconite orebody are very slight.
- The examination of the vertical sections facilitated the empirical selection of desirable flight line spacings and mean terrain clearances for future airborne and ground magnetic exploration in the Labrador Trough.
- The magnetic sections are useful to explain the nature of an anomalous magnetic field and to provide a visual answer to the aperture of the solid angle of instrumental sampling of the magnetic information.

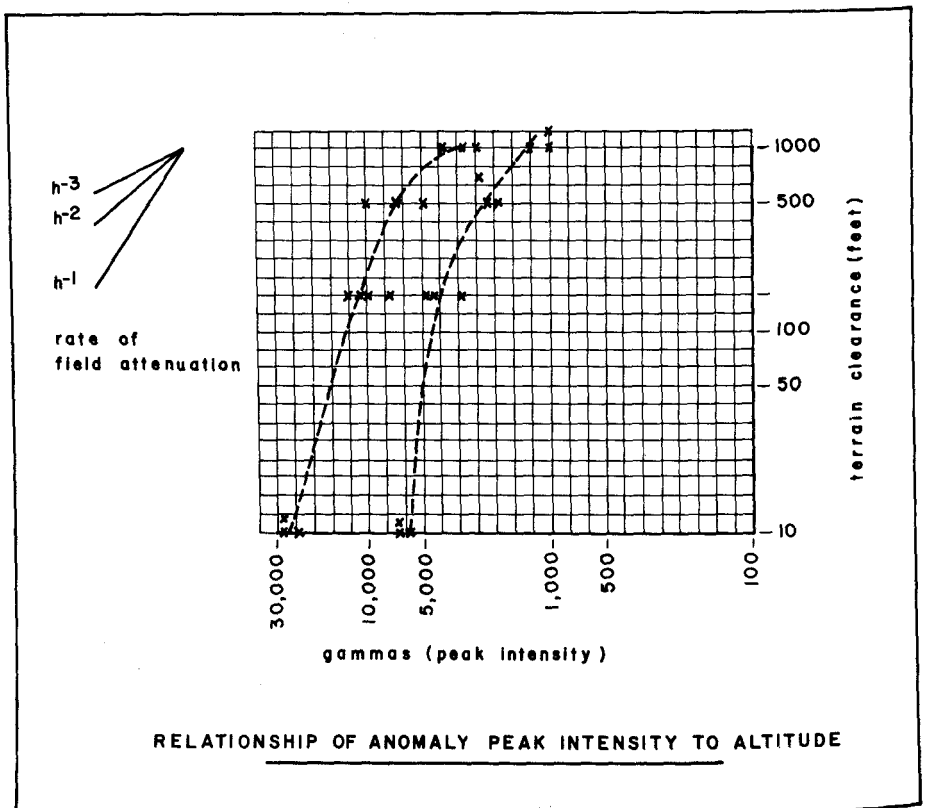


Figure 9

*Relationship of anomaly peak intensity to flight height. The curve to the left applies to steeply dipping thick ribbons and the one to the right to flat lying slabs.*

An appraisal of the rate of dissipation of the magnetic field intensity over different orebodies was made. Two principal categories of magnetic anomalies are encountered in the surroundings of the Schefferville area. The relatively low intensity anomalies are caused by thin slabs (400 to 500 feet; 120–150 m) of flat lying beds of magnetic iron formation on the westernmost edge of the trough while the higher intensity anomalies are due to thicker ribbons of steeply dipping (folded and faulted) members of magnetic iron formation in the central sector (main mine zone) of the trough. In the first case, there is very little fall-off in anomaly strength at small distance (200 to 300 feet; 65–100 m) and it is approximately equal to the inverse first power ( $h^{-1}$ ) for the altitude between 300 and 1000 feet (100–300 m) (see Figure 9). In the second case, the dissipation of the magnetic field is slightly smaller than the inverse first power of the altitude between surface and 350 feet (110 m) of depth; it is of the order of the inverse second order between 350 and 1000 feet (110–300 m). The differing fall-off rates as well as shapes and sizes of the magnetic sections are characteristic of the types and structural features of the different categories of magnetic taconite deposits.

#### **Approximations used in the calculation of the depths of burial and widths of orebodies:**

Contrary to the cases presented in this paper, only the magnetic anomaly over a potential orebody is known before obtaining direct knowledge of a proven orebody through trenching, test pitting, surface and grab sampling as well as test and tonnage drilling. The geologist is faced with the problem of determining the economic significance of an anomaly and arriving at a definite appraisal leading to the decision of an expensive test and tonnage drilling program. However, the number of anomalies surpasses the number of orebodies by a factor of 50–70 to one in a selected promising area of the Schefferville district.

Numerous approximation rules previously developed by the geophysicists are helpful in the magnetic evaluation task. A great deal of the formulae originated from calculations and magnetic studies of magnetic bodies of simple geometric configuration such as single poles, dipoles, spheres, prisms, vertical dykes, dipping ribbons, sub-horizontal slabs, etc. . . . devoid of magnetic background (noise) conducted in the space or wavenumber domain. In nature, however, the different parameters are seldom as well defined. Shapes, sizes, depths of burial, depth extents, magnetic polarizations (induced and natural remnant components) of causative bodies as well as the background magnetic noise of the surrounding country rock types are some of the unknown. To handle such a wide variety of situations, the geophysicist must rely on approximation rules. The great number and category of cases containing magnetic information obtained at different levels provide an exceptional test for the above mentioned approximations.

#### **Determination of the depth of burial:**

Different approximation formulae were used to determine the depth to the top of different types of magnetic taconite bodies for several altitudes of observation. The

rules selected for test in this paper were originally discussed in detail by Peters (1949), Dobrin (1960) and Sanker-Narayan (1961). Certain of these rules were derived to analyze vertical intensity magnetic data only. However, except for the ground magnetic data for which the vertical magnetic component was observed, only total magnetic airborne information was gathered in the different surveys. Since the vertical magnetic component represents about 95% of the total field in this northern sector of Canada, very little error is involved when using the above mentioned formulae.

Peters rule based on the induction theory and which assumes a vertical slab with infinite depth and occasionally the slope distance rule (i.e. the depth of the top of the magnetic body is equal to the horizontal distance between lower and upper points of straight segment of flank of curves) give calculated heights to top of the orebody that agree fairly well with the actual terrain clearance (see Table I). The half-width rule and consequently Hannel, Thalén and Tiburg rules yielded poorer agreement with actual depths to top of orebodies; in all cases, the calculated values are too large.

**Table: I**  
Actual depth to Top of Orebody

140	250	500	1000 (Feet)		140	250	500	1000 (Feet)	
Area: Knob Lake Ridge					Howells River				
Calculated depth to top of orebody using Peters Rule.									
<u>Section</u>					<u>Section</u>				
60	135	265	575	1200	853	230	335	450	1050
81	165	310	460	950	877	170	310	540	1120
102	180	330	455	940	893	180	290	490	960

#### Calculation of the width of the orebodies:

The southwest-northeast multilevel profiles were used to make trial calculations of the width of many orebodies. The rule -of-thumb used in this trial assumed that the width of the orebody equals the horizontal distance between the anomaly flanks at an amplitude equal to half the maximum deflection. The data appear on Table II. In the case of flat-lying magnetic bodies like the one encountered in the Howells River area, the calculated widths are always slightly smaller than the actual widths. A good part of this discrepancy can be explained easily by the poor magnetic response over the thin iron formation wedge on the western limit of the deposit. In the case of steeply dipping magnetic bodies like the ones in the Knob Lake Ridge area, the calculated widths may be smaller or larger than the actual widths depending on the proximity and influence of neighbouring magnetic bodies. It is apparent that in this case the rule applies only to observations made from surface to approximately 1000 feet. Beyond this and occasionally 500 feet, the agreement becomes increasingly poor. This rule appears to be applicable only when the width of the orebody is greater than or equal to the distance from which observations are made.

**Table: II**  
Approximate Actual (a.w.) & Calculated Widths (c.w.) of Orebodies expressed in Feet

Nominal Terrain									
Clearance (Ft):		140	250		500		1000		
Knob Lake Ridge									
Section	(a.w)	(c.w)	(a.w)	(c.w)	(a.w)	(c.w)	(a.w)	(c.w)	
60	550	600	550	680	550	800	550	—	
	400	650	400	750	400	—	400	—	
81	850	600	850	900	850	960	850	—	
	1350	1050	1350	1260	1350	1520	1350	—	
120	860	710	860	840	960	950	860	—	
	950	1200	950	1080	950	1300	950	—	
Howells River									
853	6700	5900	6700	5200	6700	6100	6700	6500	
877	7700	7100	7700	6600	7700	5200	7700	4600	
893	5600	4800	5600	4900	5600	4600	5600	4200	

**Semi-quantitative determination of the relative importance  
of the natural remanent magnetic component:**

In the Schefferville area, the magnetic inclination is approximately  $78^{\circ}\text{N}$  and the magnetic declination  $30^{\circ}\text{W}$ . As all the magnetic iron formations of this region can be considered as finite thick dipping ribbons striking roughly  $310^{\circ}$  with respect to the astronomical north, the most important parameters affecting the true shape of a magnetic anomaly are the strike of the formation with respect to the magnetic north which is on the average  $20^{\circ}\text{W}$  and the field inclination which is  $78^{\circ}\text{N}$  (Martin, 1966). Other parameters affecting the shape of an anomaly are the length to depth (of burial) ratio, the depth extent to depth (of burial) ratio and the dip (Aero Service Ltd., 1968). In the interpretation procedure, the ribbons are assumed to be uniformly magnetized in the direction of the applied geomagnetic field and the remanence (NRM) effect is considered as being negligible.

The construction of magnetic sections allows the interpreter to visualize and estimate the approximate direction and relative importance (intensity ratio) of the NRM component. In the Howells River area where the iron formations are dipping approximately  $10^{\circ}\text{NE}$ , the steepest gradient is located to the northeastern side on the magnetic sections No: 853, 877 and 893 and the magnetic low (negative sector) is located to the northeastern as well. Both the steepest gradient and the magnetic low are located on the wrong side of the magnetic dipping plate indicating that the magnetic strike of  $20^{\circ}\text{W}$  and the field inclination of  $75^{\circ}\text{N}$  are wrong. On the other hand, the displacement of the peak of the anomaly with increasing terrain clearance is located to the northeast as expected. This means that another magnetic vector component is superimposed on the amplified induced magnetic field. A NRM vector oriented at approximately  $90^{\circ}$  with the induced magnetic vector (i.e. pointing towards the west)



and having a subhorizontal inclination ( $0^{\circ}$ – $20^{\circ}$ N) allows the correct interpretation of the anomaly pattern of the magnetic sections.

In the Knob Lake Ridge area, the magnetic iron formations are dipping  $50^{\circ}$  to  $70^{\circ}$ NE. Except for section No: 60 which was selected in view of its peculiar anomaly pattern, the steepest gradients and magnetic lows are located to the northeastern side in spite of the fact that the dip of the formations averages  $50^{\circ}$  to  $60^{\circ}$ NE. The ore section located within the southwestern magnetic iron formation block of sections: 60, 81 and 102 depict a normal anomaly pattern with the steepest gradients and anomaly lows on the southwestern edge and northeastern displacement of the anomaly peak with increasing terrain clearance; these factors indicate that the NRM component effect is negligible within this block. This does not hold true for the three other magnetic blocks located to the northeast of the previous one. In this last case, a NRM vector oriented in the western direction and slightly inclined above the equator can easily explain the anomaly pattern of the magnetic sections of the Knob Lake Ridge area.

### Acknowledgments

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### Résumé

Nous avons effectué des levés terrestres et aériens à diverses altitudes de vol au-dessus de gisements de taconite magnétique. Nous présentons les données magnétiques sous forme de profils. Ces données permettent d'optimiser sur les lieux de l'expérimentation l'espacement entre les lignes de vol et l'altitude de vol de levés magnétiques aéro et héliportés en production ou qui sont planifiés pour le futur.

Ces renseignements permettent de déterminer la largeur de la masse causative, la profondeur d'enfouissement sous la surface terrestre et l'importance relative de la composante rémanente naturelle. Plusieurs exemples tirés d'une grande variété de terrains où se trouvent des gîtes éventuels de taconite magnétique permettent d'établir une comparaison des paramètres calculés, à savoir les profondeurs d'enfouissement, largeurs et al rémanence naturelle, avec ceux que l'on observe. Nous montrons quelques-uns des nombreux profils magnétiques étudiés dans cette région.

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